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Members of the Department of Defense Explosive Safety Board (DDESB) and the Tri-Services Joint Hazard Classifiers (JHC) have been revising the current Department of Defense Ammunition and Explosives Hazard Classification Procedures: Joint Technical Bulletin TB 700-2/NAVSEAINST 8020.8B/TO 11A-1-47/DLAR 8220.1.[1] Some of the proposed revisions to the test protocols outlined in this document, (hereafter referred to as TB 700-2) are more conservative and will be more costly to implement than the previous ones. These changes could have a profound impact on the solid rocket community involved with the research and development and manufacture of solid rocket propellants and motors; particularly, those to be shipped or placed in DoD storage facilities. The ramifications may include higher development costs and storage limitations for solid rocket propellants and motors. This paper outlines past TB 700-2 revisions, the current TB 700-2 hazard classification requirements and protocols, changes of concern to the proposed TB 700-2 Revision Final Draft [2] and the possible ramifications to the solid rocket community.

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Comments and Position Regarding the Proposed TB 700-2 Rewrite Dated June 2007

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Members of the Department of Defense Explosive Safety Board (DDESB) and the Tri-Services Joint Hazard Classifiers (JHC) have been revising the current Department of Defense Ammunition and Explosives Hazard Classification Procedures: Joint Technical Bulletin TB 700-2/NAVSEAINST 8020.8B/TO 11A-1-47/DLAR 8220.1.[1] Some of the proposed revisions to the test protocols outlined in this document, (hereafter referred to as TB 700-2) are more conservative and will be more costly to implement than the previous ones. These changes could have a profound impact on the solid rocket community involved with the research and development and manufacture of solid rocket propellants and motors; particularly, those to be shipped or placed in DoD storage facilities. The ramifications may include higher development costs and storage limitations for solid rocket propellants and motors. This paper outlines past TB 700-2 revisions, the current TB 700-2 hazard classification requirements and protocols, changes of concern to the proposed TB 700-2 Revision Final Draft [2] and the possible ramifications to the solid rocket community.

DISCLAIMER

This paper does not present Air Force or Air Force Research Laboratory (AFRL) policy. The observations and opinions discussed in this paper are shared by many members of the Joint Army Navy NASA Air Force (JANNAF) and solid rocket communities; however, they are presented as the author's.

INTRODUCTION

Past revisions to TB 700-2 have raised concerns from members of the solid rocket community in the following areas:

- The full-scale test article requirement of the United Nations (UN) Test Series 6 protocol, in the January 1998 revision
- The UN Test Series 6 fragment throw restrictions in the January 1998 revision
- The zero card requirement of the alternate (shock sensitivity) tests in the January 1998 revision

Workshops sponsored by the JANNAF Interagency Propulsion Committee served as a forum for technical discussions to address the concerns listed above and develop new acceptable alternate test protocols for hazard classifying large rocket motors. Technical discussions and workshops by members of two JANNAF subcommittees: Propulsion Systems Hazards Subcommittee (PSHS) and Propellant and Explosives Development and Characterization Subcommittee (PEDCS), focused on developing alternate hazard classification protocols in three areas with the following characteristics:

- Shock sensitivity and critical diameter tests indicative of credible storage and transportation threats.
- A subscale fast cook-off protocol that could be correlated with the full-scale fast cook-off tests required under UN Test Series 6.
- Development of an alternate test protocol to assess the effects of damaged propellants and DDT potential.

As a result of the interaction between the JANNAF community, DDESB and JHC, progress has been made with an acceptable alternate shock test protocol with a more credible shock stimulus and level of confinement incorporated into the 2002 revision of TB 700-2. The intent of this paper is to raise the awareness of solid rocket community members of the potential impact of the 2007 proposed revision of TB 700-2 and once again unite and work together with DDESB and JHC to make revisions to TB 700-2 that reflect more credible hazard classification protocols for addressing ammunition, explosives and solid rocket propellant/motor hazards for storage and transportation.

BACKGROUND

In January 1998, DDESB/JHC revised their Final Hazard Classification (FHC) guidelines; requiring more stringent fragment throw restrictions, shock sensitivity testing and requiring full-scale test articles for fragment throw/impact determination in the fast cookoff bonfire test. The 1998 revision also changed the dividing line between Hazard Division (HD) 1.1 and 1.3 propellants in the alternate test methods protocol for hazard classifying large rocket motors (that are transported individually). Under the pre 1998 guidelines, if a propellant did not detonate when a 1.44-in ID, steel-confined cylinder of propellant was subjected to a shock stimulus of $\geq$70 kbar (>1,015,264.21 psi), it was considered HD 1.3. Under the 1998 guidelines for shock sensitivity, that value rose to >250 kbar (>3.5 Mpsi) applied over a 7-in diameter propellant surface area, in a heavily confined configuration (this test is known as a Super Large-Scale Gap Test or SLSGT).

In January 2002, the DoD alternate test procedures for hazard classifying large rocket motors (that are transported individually) were revised, lowering the dividing line between HD 1.1 and 1.3 propellants back down to the 70 kbar shock stimulus for two of the three options but requiring shock sensitivity testing at either 150% of the unconfined critical diameter (D_c) (minimum of 5 inches), or motor diameter (see figures 1-3). The 1998 changes only applied to hazard classifying rocket motors used in new DoD systems; however, in 2002, the Department of Transportation (DOT) started requiring the DoD test protocols for hazard classification of commercial rocket motors as well.

If the dividing line between HD 1.1 and 1.3 propellants had not been lowered back down to the 70 kbar shock input, the change would have severely impacted the solid rocket community. The impacts to DoD and the solid rocket community would have been: higher life cycle costs, lost government and contractor capabilities and because of reduced rocket motor performance, greater risk to the warfighter and loss of payload capability for space boost and future strategic boosters.

Hazard Classification Requirement

Per the current and past TB 700-2 requirements, for Ammunition and Explosives (AE) the sponsoring DoD organization must obtain either a FHC, Interim Hazard Classification (IHC) or adhere to the conditions listed in TB 700-2 section under "Storage and Transportation without DoD IHC or FHC." The conditions listed are other types of hazard classification and consist of the following:

- IHC assigned by DOE
- FHC assigned by DOE
- DOT hazard classification obtained by the manufacturer of commercial explosive products
- Local Classification in manufacturing, research, development, test or evaluation environments
    - Local classification procedures/documentation established by the Service Hazard Classifier
    - Not for off-base transportation of AE

FHC and IHC issued by or to the DoD or DOE are only valid for transportation and storage of AE by DoD and DOE, DoD and DOE contractors or subcontractors (with a contract authorizing possession of the AE). The methods used to obtain a FHC of an AE are:

- Hazard classification by Test
- Hazard classification by Analogy
- Hazard classification as Pre-1980 AE
- Hazard classification as Not New AE
- Hazard classification by Predominant Hazard
- Hazard classification by 49 CFR 173.56(h)

Prior to the 1998 TB 700-2 revision, many of the rocket motors utilized in DoD systems were FHC or IHC by analogy to a similar AE that had been classified by test. While still allowed, by DDESB/JHC, FHC by analogy is becoming more difficult because not only must the analogous AE be similar to the parent AE, but the new article's shipping/storage container must also be analogous to that of the parent AE.

Hazard classification by Test uses test data on the specific AE and shipping/storage container to assign the FHC. Since the 1998 TB 700-2 revision, it is the DDESB/JHC preferred method for FHC. The cost impact of hazard classification by test can be demonstrated by the U.S. Army Space and Missile Defense Command (USASMDC) spending over $100M to obtain the Insensitive Munitions (IM) assessment and FHC for the rocket motors in their Ground Based Midcourse Defense (GMD), Patriot Advanced Capability-3 (PAC-3) and Theater High Altitude Area Defense (THAAD) missile defense systems.

Hazard Classification of New Substances

Hazard classification for new substances (Unpackaged propellants and explosives) performed by test begins with the application of the United Nations (UN) Series 3 tests to answer the question "Is the substance thermally stable and is the substance too hazardous for transport in the form tested?" FHC and IHC must be supported by negative results (pass) from the following TO 11A-1-47 UN Series 3 test procedures:

- UN Test 3(a)(i) Impact Test
- UN Test 3(b)(iii) ABL Friction Test
- UN Test 3(c) Thermal Stability Test
- UN Test 3(d)(i) Small Scale Burning Test

Hazard Classification of New AE

Hazard classification for new AE (AE, packaged AE or packaged substance) performed by test begins with the application of the UN Series 4 tests to answer the question "Is this AE, packaged AE or packaged substance too hazardous for transport?" FHC and IHC must be supported by negative results (pass) from the following TO 11A-1-47 UN Series 4 test procedures (if they have not been subjected to UN Test Series 3):

- UN Test 4(a) Thermal Stability Test for Articles and Packaged Articles
- UN Test 4(b)(i) Steel Tube Drop Test for Liquids
- UN Test 4(b)(ii) Forty Foot (Twelve Meter) Drop Test for Articles and Solid Substances

Final Hazard Classification of AE Into Hazard Divisions 1.1, 1.2, 1.3 and 1.4

Under the previous TB 700-2 guidelines, assignment of FHC for new AE was performed under UN Test Series 6 to answer the question "Which Hazard Division (1.1, 1.2, 1.3 or 1.4) corresponds most closely to the behavior of the product?" UN Test Series 6 includes assessment of the article's response to internal ignition/initiation, propagation of burning or explosion and a fast cook-off fire test. The following tests make up the UN Test Series 6 protocol:

- UN Test 6(a) Single Package Test (Determines if hazardous effects are apparent outside the package when a single AE is detonated or ignited)
  - 1st trial: #8 blasting cap (0.5 g explosive) to initiate internally
  - 2nd and 3rd trials: internal ignition using the article's own ignition device
    - For rocket motors a static test was allowed
- UN Test 6(b) Stack Test (Determines whether burning or explosion in one package in the stack is propagated to the other packages, and in what way the surroundings could be endangered by this event)
  - At least three articles are required for this test
  - As with the single package test, a detonator or igniter is used in the stack test to initiate one article. The other packages/articles are situated in the configuration in which they are to be shipped. The criteria for classification for the stack test are similar to those for the single package test. The basic criterion for a HD 1.1 designation is the explosion of virtually the entire contents of the articles.
- UN Test 6(c) External Fire (bonfire) test (Determines the hazard response when AE in shipping containers are subjected to a fast cook-off environment

Alternate Hazard Division Assignment Tests

One of the major concerns of UN Test Series 6 is that many of the full-scale tests are not appropriate for large solid rocket motors. To address this concern, DDESB/JHC allowed an alternate test protocol for large rocket motors that are only transported individually. The revised alternate test protocol allows you to conduct the external fire test on a single article as it is configured for transportation, to include any packaging. If you elect not to perform single package and stack testing, you can either submit an alternate test plan in accordance with paragraph 3-2.*g*. of TB 700-2 or conduct one of the three shock sensitivity tests listed below, followed by external fire testing.

Shock Sensitivity Test, Option 1

The shock sensitivity test in option 1 is a modified version of the Super Large-Scale Gap Test (SLSGT) used in the 1998 TB 700-2 alternate test protocol. The modifications include an increase in length to an L/D of 4, addition of velocity pins and the option of using a conical shaped booster charge. As with the 1998 TB 700-2 alternate test protocol, the test is conducted at a zero gap. A schematic of the SLSGT is shown in figure 1.

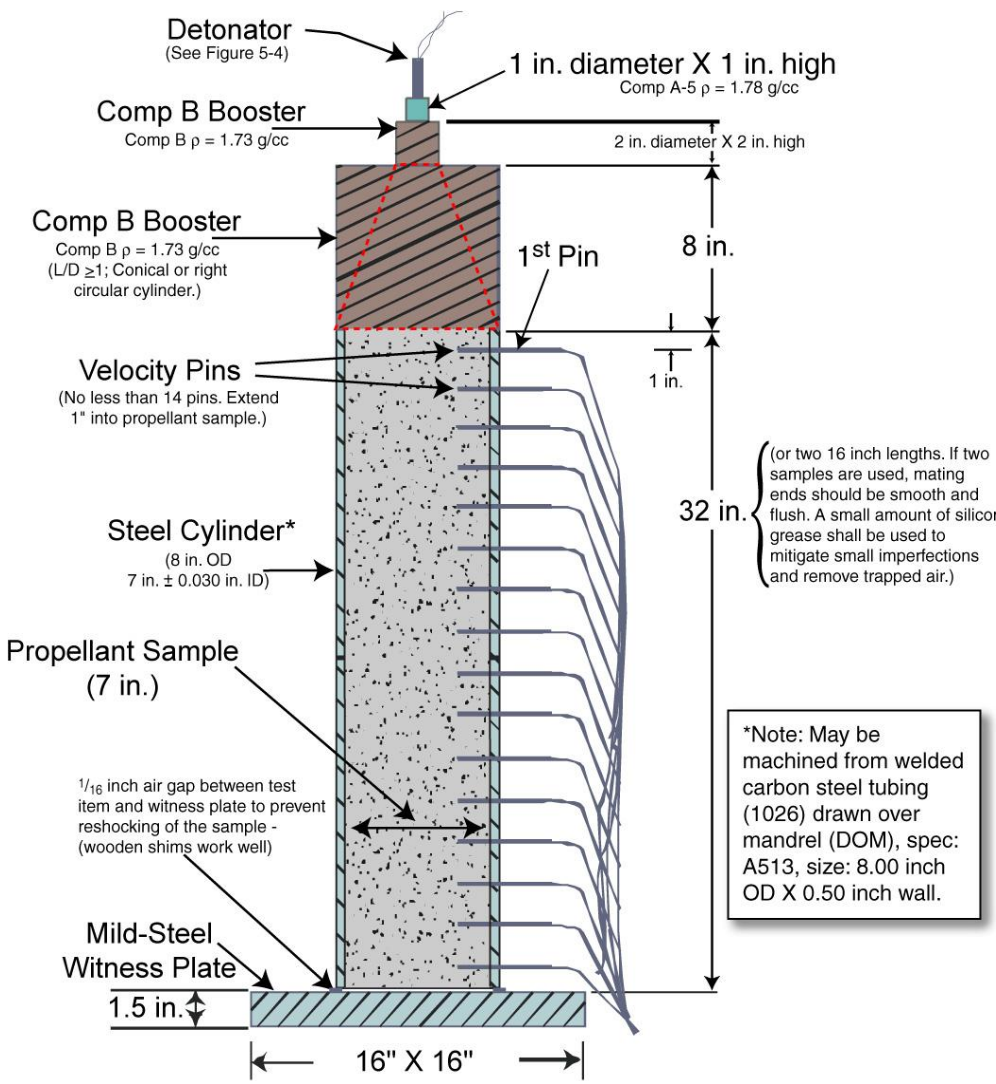


Figure 1. Super large-scale gap test configuration

One test is required and propellants that maintain a stable detonation as indicated by the velocity pins and the witness plate are hazard classified as HD 1.1. To be a HD 1.3 candidate, the propellant must exhibit a decaying reaction approaching sonic velocity. A hole in the witness plate or significant fracturing of the witness plate is evidence of HD 1.1.

Shock Sensitivity Test, Option 2

This option requires that you first establish a sample size at or above critical diameter (D_c) followed by a 70 kbar shock sensitivity test at or above one-and-a-half times that size.

An Unconfined Critical Diameter Test provides the data to be used in determining the diameter for the following Gap Test. A schematic of the Unconfined Critical Diameter Test is shown in figure 2.

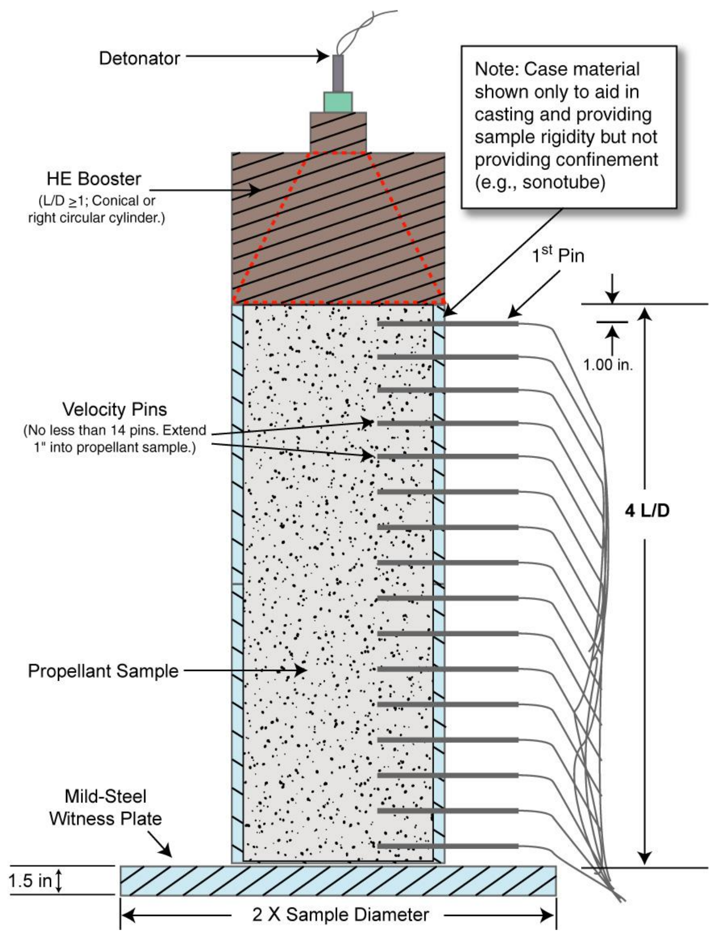


Figure 2. Unconfined critical diameter test configuration

The test protocol for the Unconfined Critical Diameter Test states that for any sample diameter at which a stable detonation occurs as evidenced by the velocity pins and the witness plate, that diameter is considered to be at or above D_c.

The test protocol for Test Option 2 states that the sample diameter shall be a minimum of 5 inches, or at least 150% of the unconfined critical diameter of the propellant (demonstrated as specified above), whichever is greater. Preparation of the sample must be such that motor propellant is accurately represented. The sample must be contained in a case that affords confinement equivalent to that of the rocket motor case. One test shall be conducted at 70 kbar shock pressure at the output end of the gap material (as input to the propellant sample under test). A schematic of the Option 2 Gap Test is shown in figure 3.

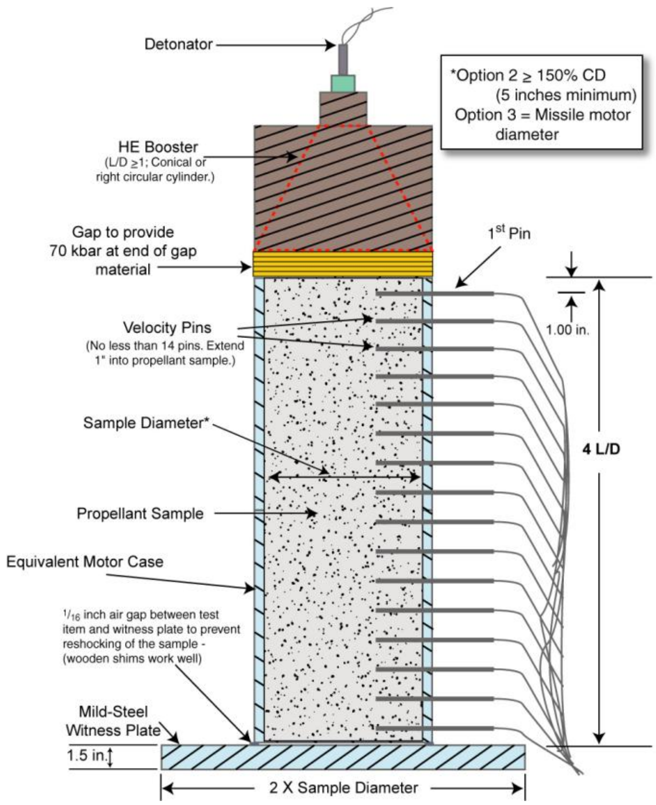


Figure 3. Gap test (≥150% CD or Motor Diameter) configuration

One test is required and propellants that maintain a stable detonation as indicated by the velocity pins and the witness plate are hazard classified as HD 1.1. To be a HD 1.3 candidate, the propellant must exhibit a decaying reaction approaching sonic velocity. A hole in the witness plate or significant fracturing of the witness plate is evidence of HD 1.1.

Shock Sensitivity Test, Option 3

The test protocol for Test Option 3 states that the sample diameter shall be equal to motor diameter. Preparation of the sample must be such that motor propellant is accurately represented. The sample must be contained in a case that affords confinement equivalent to that of the rocket motor case. One test shall be conducted at 70 kbar shock pressure at the output end of the gap material (as input to the propellant sample under test). The test criteria and reporting requirements are the same as for Option 2. A schematic of the Option 3 Gap Test is also shown in figure 3.

Interim Hazard Classification

Hazard classification for new substances and articles may be issued under an IHC for several reasons including:

- R&D
- Foreign AE exploration
- Demilitarization
- FHC in process

Under the previous TB 700-2 guidelines, assignment of an IHC for a substance required the following:

- UN Test 3 (a) (i) (Impact Test)
- UN Test 3 (b) (iii) (ABL Friction Test)
- UN Test 3 (c) (Thermal Stability Test)
- UN Test 3 (d) (i) (Small Scale Burning Test)

In addition, the following TB 700-2 test procedures were required to obtain an interim Hazard Division (HD) 1.3 classification:

- Test 2(a)(iii) Gap Test (Naval Ordnance Lab gap test most widely used)
    - HD 1.1 if a positive response is given at $\geq$ 70 cards
    - HD 1.3 at $\leq$ 69 cards
- Test 5(a) Cap Sensitivity Test
    - HD 1.1 if a positive response is given with a standard detonator (#8 blasting cap)
    - HD 1.3 if a negative response is given with a standard detonator

Current Revision to TB 700-2

One of the major changes in the TB 700-2 Rewrite Final Draft (30 June 2007) is a new "Harmonized" test protocol for obtaining FHC and IM assessment for AE. Under the previous TB 700-2 guidelines, assignment of a FHC other than HD 1.1 was conducted under UN Test Series 6, which was mandatory for HDs 1.1 (Mass explosion), 1.2 (Non-mass explosion, fragment producing), 1.3 (Mass fire, minor blast, or fragment) and 1.4 (Moderate fire, no blast, or fragment), and was the series that discriminated between the Class 1 divisions.

The "Harmonized HD 1.1, HD 1.2, HD 1.3, and HD 1.4 Assignment Tests" in the TB 700-2 Rewrite Final Draft (November 2005) consist of the three main tests that still require full-scale test articles in their shipping containers:

- UN Test 6(a) Single Package Test
    - 1st trial (Unconfined): *For rocket motors and artillery propelling charges, initiate the donor with an external source approved by the Service Hazard Classifiers (JHC) and DDESB.*
    - 2nd trial (Confined): Confinement containers are placed around the package. A minimum thickness of confinement packages of 1.5 ft (0.5 m) for a package not exceeding 5.3 ft^3 (0.15 m^3) or 3 ft (1 m) for a package greater than 5.3 ft^3 (0.15 m^3) must be used. (NOTE: Alternative methods of confinement are to use boxes or bags filled with earth or sand placed around and on top of the package, or to use loose sand around the package. The minimum thickness requirements apply). *For rocket motors and artillery propelling*

charges, initiate the donor with an external source approved by the Service Hazard Classifiers (JHC) and DDESB.

- UN Test 6(b) Sympathetic Reaction Test
  - 1st trial (Unconfined): A stack of AE with a minimum volume of 5.3 ft^3 (0.15 m^3) or at least two acceptor packages, whichever is greater in volume, must be tested. *For rocket motors and artillery propelling charges, initiate the donor with an external source approved by the Service Hazard Classifiers (JHC) and DDESB.*
  - 2nd trial (Confined): For the confined trial, containers similar in shape, size and density to the packaged AE should be placed as closely as possible around the donor and acceptor AE. The confinement containers should provide a minimum 3 ft (1m) confinement thickness in every direction. (NOTE: Alternative methods of confinement such as boxes or bags filled with earth or sand, loose sand placed around and on top of the stack, or a hole recessed into the ground may be used. If loose sand is used for confinement, the stack should be covered or protected to ensure that no sand falls between adjacent packages or non-packaged AE.) AE without packaging should be confined in a manner analogous to that used for packaged AE. For rocket motors and artillery propelling charges, initiate the donor with an external source approved by the Service Hazard Classifiers (JHC) and DDESB.

- UN Test 6(c) Liquid Fuel/External Fire Test
  - For AE transported in multiples, stack the AE in their transportation and storage configuration (e.g., pallet or unit load) with a total volume of at least 5.3ft^3 (0.15 m^3) or a minimum of three packages, whichever is the greater.
  - For large rocket motors transported individually, only a single test article is required.
  - Requires a quantity of fuel sufficient to maintain a fully developed fire for 150% of the estimated time required to cause all AE to react.

DISCUSSION

Current Revision to TB 700-2 Changes of Concern

The proposed protocols in the TB 700-2 Rewrite Final Draft (June 2007) that give cause for concern are the following:

- FHC protocol
  - UN Test 6(a) Single Package Test
  - UN Test 6(b) Stack Test
- Interim Hazard Classification (IHC) protocol
  - Additional hazard classification test data
  - Proposed classification only for "articles"

The first proposed protocol change in the TB 700-2 rewrite that gives cause for concern is the one shown in italics for both the UN Test 6(a) Single Package and UN Test 6(b) Sympathetic Reaction Tests (*For rocket motors and artillery propelling charges, initiate the donor with an external source approved by the Service Hazard Classifiers (JHC) and DDESB.*) In conversations with the Air Force representative of the JHC, he stated that no longer will a static test firing be allowed to satisfy this test requirement for rocket motors.[3] The Air Force JHC also stated the external initiation sources that DDESB/JHC is seriously considering for this test is a Shape Charge Jet (SCJ).[3]

DDESB/JHC have also given consideration to using a Rocket Propelled Grenade (RPG) for the external initiation source. [3] This new requirement along with the 1998 changes to TB 700-2 show a historical trend for DDESB/JHC to require more stringent testing incorporated into the FHC protocols for assignment of the appropriate Hazard Division.

Under the old UN Test Series 6 protocol, the only shock stimulus consisted of the blasting cap tests in the 6(a) Single Package and UN Test 6(b) Sympathetic Reaction Tests. If the manufacturer of the AE wanted to avoid stringent shock initiation testing they could spend more money and utilize more test assets by running the UN Test Series 6 protocol instead of the alternate test protocol.

By adding the proposed external initiation sources that DDESB/JHC are seriously considering, this will negate this option by significantly raising the external stimulus applied to the test articles for a threat that is clearly not credible for a storage and transportation threat. SCJ and RPG threats are credible only for battlefield (IM) and terrorist scenarios. In addition, the proposed change will add significant cost to a test series that already costs several million dollars to run.

The second major change in the TB 700-2 rewrite is a new protocol for obtaining an IHC for AE. The IHC procedures in the latest TB 700-2 rewrite call for the following:

- At a minimum, UN Series 3 or UN Series 4 test results or a statement of the rationale supporting the conclusion that the AE is not forbidden for transportation is required.
- *Additional hazard classification test data may be required to support an IHC of other than HD 1.1.* The additional tests will be dependent on the AE configuration and may include tests such as:
  - The NOL Card Gap Test
  - ARDEC Solid Propellant Initiation Sensitivity Test
  - Expanded Large Scale Gap Test
  - Super Large Scale Gap Test
- Analogies to existing AE with FHC may be used for assigning IHC

Under the old IHC protocol, the NOL card gap test was used as the discriminator between HD 1.1 and HD 1.3 for assigning an IHC to AE, with the above change, it is now up to the Service Hazard Classifiers (JHC). In past conversations with the JHC they have expressed concerns with using the NOL card gap test results for hazard classification stating that it does not adequately address D_c concerns. That was the reasoning for requiring the SLSGT in the January 1998 TB 700-2 rewrite of the alternate test procedures.

The new change to the IHC protocol paves the way for more stringent shock test requirements. This should be a wake-up call for the IHPRPT program and all propellant development efforts that claim a HD 1.3 formulation based on the old NOL card gap test results of HD 1.3 at $\leq$ 69 cards.

In the same conversation with the Air Force representative of the JHC mentioned above, he also stated that DDESB is opposed to recognizing an IHC of other than HD 1.1 to substances (propellants) unless the candidate propellant has passed a shock test or D_c test at the largest geometry/dimension of the container they could be cast into.[3] This information was substantiated by a colleague from another DoD propulsion lab who made a presentation at a recent IM meeting and was critiqued by an official from DDESB for his reference to propellant classification. He was told that the new regulations do not allow for propellant classification, only system classification.

The apparent trend of DDESB/JHC becoming more conservative when granting FHC and IHC was also demonstrated when the U.S. Air Force Academy (USAFA) applied for an IHC for their composite cased, HTPB/AP/Al, Falcon rocket motor. Because of my experience in solid propellant/motor hazards assessment and classification, I was asked to assist the USAFA in obtaining an IHC from the Air Force Safety Center (AFSC/SEW).

The HTPB/AP/Al formulation used in the Falcon rocket motor contains no nitramines or other energetic ingredients and has a relatively low solids loading (~84%). With the typical D_c of a generic HTPB/AP/Al formulation being >50 inches, there is nothing about this formulation that should raise any concern about $D_{c,}$ especially given the fact that the Falcon motor diameter is <7 inches.

I used the USAFA Falcon motor data package and wrote a request for hazard classification by close analogy to the Atlas V solid rocket booster motor that AFSC/SEW had classified as HD 1.3C. When I presented the proposed request for IHC by close analogy package to AFSC/SEW, I was informed that even though the Atlas V solid rocket booster motor had been classified as HD 1.3C by AFSC/SEW, they would prefer that I use a parent formulation that had passed the SLGT. Fortunately, I was able to get all of the data for the propellant formulation used in the Orion QDL-1 rocket motor from a colleague at ATK.

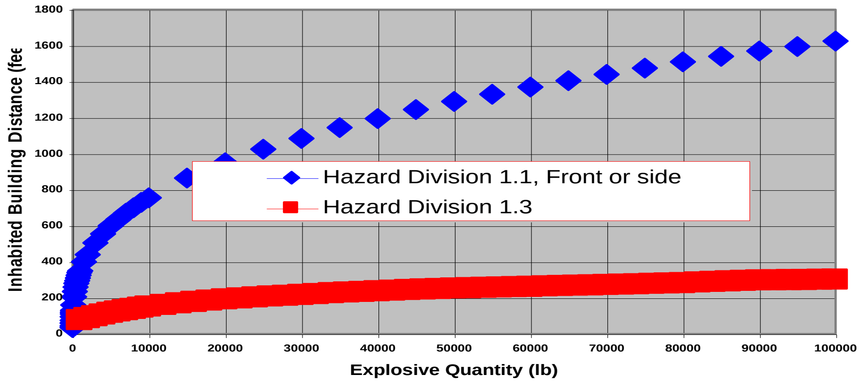
When I resubmitted the request package for IHC by close analogy to the QDL-1 parent item that had passed the SLSGT, AFSC/SEW granted the Falcon motor an IHC of HD 1.3C. This experience reinforces the belief that DDESB/JHC not only favors overly conservative shock tests but are requiring them more than ever.

This proposed change to the test protocol for obtaining an IHC could have a very serious impact on the solid rocket community involved with the research and development and manufacture of solid rocket propellants and motors; particularly, those to be shipped or placed in DoD storage facilities. As stated previously, DDESB requires all DoD facilities to have either a FHC or an IHC for all explosive items stored there. If DDESB is making it more stringent to obtain an IHC of other than HD 1.1 this will greatly impact R&D operations for new solid propellants and energetic ingredients.

If AFRL were forced to perform a SLSGT or sample diameter size shock test on every candidate formulation made in our propellant laboratory (to get an IHC of other than HD 1.1), the cost and resources required would be cost prohibitive. An NOL gap test requires approximately 0.6 pounds of propellant and could be made in a pint mixer. A SLSGT requires approximately 82 pounds of propellant and requires a 5 gallon mixer. Not all mix facilities have 5 gallon mixers and not all test facilities have the capability of running a SLSGT. The cost of running a SLSGT is approximately $20K. The cost of running an NOL gap test is over an order of magnitude less. That is why the NOL test has been used for decades as a screening test in propellant development programs and in the pre 2007 TB 700-2 protocol for obtaining an IHC.

The alternative of accepting an IHC of HD 1.1 on all of our candidate formulations is out of the question due to the much more stringent quantity distance (QD) requirements for HD 1.1 vs. HD 1.3 propellants (See figure 4).

Explosive regulations mandate that when HD 1.1 AE is stored with HD 1.3 AE, all of the AE stored together must use the HD 1.1 QD requirements. If all of the new candidate propellant formulations were treated as HD 1.1, neither AFRL nor most of the solid propulsion community could comply with the increased QD requirements.



CONCLUSIONS

The protocol change in the TB 700-2 Rewrite for both the UN Test 6(a) Single Package and UN Test 6(b) Sympathetic Reaction Tests requiring that donor rocket motors and artillery propelling charges be initiated with an external source approved by the Service Hazard Classifiers and DDESB appears to be a trend by DDESB/JHC to require more stringent initiation testing incorporated into the FHC protocol for assignment of the appropriate Hazard Division.

By adding the proposed SCJ and possibly even RPG external initiation sources that DDESB/JHC are seriously considering, this will significantly raise the external stimulus applied to the test articles for a threat that is clearly not credible for a storage and transportation threat. SCJ and RPG threats are credible only for battlefield (IM) and terrorist scenarios. In addition, the proposed change will add significant cost to a test series that already costs several million dollars to run.

The second major change in the TB 700-2 rewrite to the protocol for IHC states that additional hazard classification test data may be required to support an IHC of other than HD 1.1. The additional tests will be dependent on the AE configuration and may include tests such as:

- ▪ The NOL Card Gap Test
- ▪ ARDEC Solid Propellant Initiation Sensitivity Test
- ▪ Expanded Large Scale Gap Test
- ▪ Super Large Scale Gap Test

- Analogies to existing AE with FHC may be used for assigning IHC

The departure from using the NOL card gap test as the discriminator between HD 1.1 and HD 1.3 for assigning an IHC to AE could have a very serious impact (significant cost increase and operational restrictions) on the solid rocket community involved with the research and development and manufacture of solid rocket propellants and motors; particularly, those to be shipped or placed in DoD storage facilities. In addition, the opposition to giving an IHC of other than HD 1.1 to substances (unless the candidate substance has passed a shock test or D_c test at the sample size) also has serious implications (significant cost increase and operational restrictions) and shows the DDESB/JHC trend toward more stringent shock stimulus testing to receive a HD 1.3 classification. No longer will passing the NOL card gap test at $\leq$ 69 cards guarantee an IHC of HD 1.3.

RECOMMENDATIONS

The 2002 revision to TB 700-2 and subsequent lowering of the dividing line between HD 1.1 and 1.3 propellants back down to the 70 kbar shock stimulus was accomplished as a result of the interaction between the JANNAF community, DDESB and JHC. If a collaborative effort between the JANNAF community and DDESB/JHC is renewed, I believe it is possible to again change the proposed TB 700-2 protocols of concern to credible tests the solid propulsion community can agree to and operate with.

The key to getting more credible hazard classification protocols is to give DDESB/JHC test data they can use to make more informed decisions. With the majority of the changes to TB 700-2 addressing shock and initiation stimulus, it is clear this is a major area of concern for them.

The way forward to hazard classification protocols more indicative of credible storage and transportation threats could be accomplished by conducting shock sensitivity and critical diameter tests on families of propellants at varying levels of shock stimulus and level of confinement. If DoD and the solid propulsion contractors were willing to invest in this research, it could have a great potential for return in terms of cost reduction and increase in performance.

DEDICATION

This paper is dedicated to the memory of Dr. Robert R. Bennett. Bob was an industry recognized expert in solid propellant formulation and development, and was a dynamic and key figure in the JANNAF propulsion community efforts to develop hazard classification protocols more indicative of credible storage and transportation threats. The alternate shock test protocol for large rocket motors (with a more credible shock stimulus and level of confinement) incorporated into the 2002 revision of TB 700-2 was made possible with the tireless efforts of Bob.

REFERENCES

1. Department of Defense (DoD) Ammunition and Explosives Hazard Classification Procedures Joint Technical Bulletin TB 700-2/NAVSEAINST 8020.8B/TO 11A-1-47/DLAR 8220.1; 5 January 1998.

2. Department of Defense (DoD) Ammunition and Explosives Hazard Classification Procedures Joint Technical Bulletin TB 700-2/NAVSEAINST 8020.8B/TO 11A-1-47/DLAR 8220.1; Revision Final Draft; 30 June 2007.

3. Air Force Joint Hazard Classifier, private communication, May 2007.

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Comments and Position Regarding the Proposed TB 700-2 Rewrite Dated June 2007

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2008 DDESB Seminar

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Disclaimer

- This paper does not present Air Force or AFRL policy.
- The observations and opinions discussed in this paper are shared by many members of the solid rocket and Joint Army Navy NASA Air Force (JANNAF) community, however, they are presented as the author’s.

Hazard Classification Background

- **Recent History in Hazard Classification Procedures**
  - **On January 5, 1998, DoD released TB 700-2, NAVSEAINST 8020.8B, AF TO 11A-1-47 as a revision to NAVSEAINST 8020.8A dated December 1989**
    - **Describes test methods and criteria for defining substance and article hazards class: 1.1, 1.2, 1.3, 1.4, etc.**
    - **Applies to all explosives entering DoD system**
    - **Concerns shipping and storage of explosives only - not use**
    - **Rocket propellants specifically defined as explosives for this document**
    - **For small rockets, explosives, etc., describes UN test protocols**
    - **For large rockets, describes alternate tests**
  - **Changed to assure standardization with UN testing**

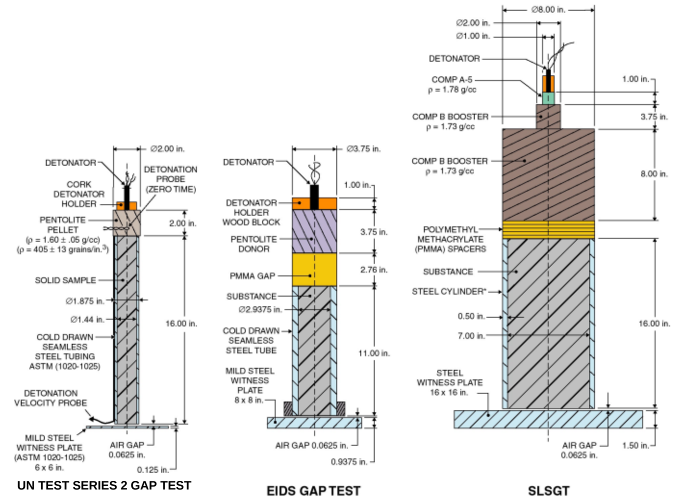
Final Hazard Classification Test Protocol (HDs 1.1,1.2.1.3 and 1.4) Pre 1998 vs. 1998 Revision

- DOT Test Series (Same as for IHC) Subscale
  - #8 Blasting cap to initiate internally
    - 0.5 g explosive
  - NOL Gap Test
    - 1.44” Diameter x 5.5” long pipe
    - 2” Diam x 2” long pentolite booster
    - <70 Cards
    - 1/8th-Inch witness plate
    - ‘Go’ criteria
      - Pipe split entire length
      - Sustained detonation velocity
      - Hole in witness plate
  - Open burning
    - 2” Propellant cubes

- Standard UN Test Series 6 (full size) each tested 3 times
  - Single Package Test
    - Test substance packed as it will be shipped
    - 1st Trial: #8 blasting cap (0.5 g explosive) to initiate internally
    - 2nd, 3rd Trials: ignite internally
      - Use article’s own ignition device (for rocket motors, it can be a static test
      - Class 1.1 if package explodes
  - Stacked Test
    - Substance packed as it will be shipped
  - Bonfire Test
    - Substance packed as shipped

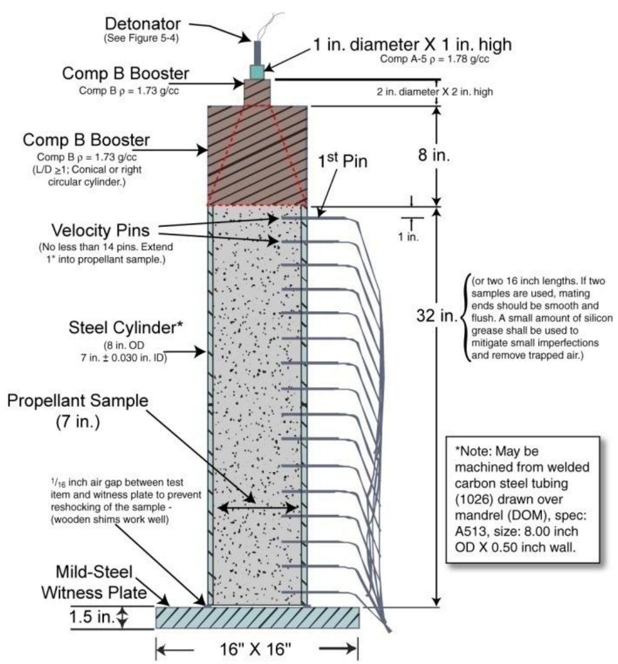
Alternate Tests to UN Test Series 6

- **Authors of TB 700-2 Recognize Impracticality of UN Test Series 6 For Large Rocket Motors**
- **2002 Alternate Tests for large rocket motors**
  - **All focus on propellant detonability (shock sensitivity)**
  - **All have varying card gaps down to zero**
  - **All have same ‘Go’ criteria**
    - **Sustained detonation velocity**
    - **Hole in witness plate**
    - **Pipe split entire length**
    - **If ‘Go’, is hazard division 1.1**



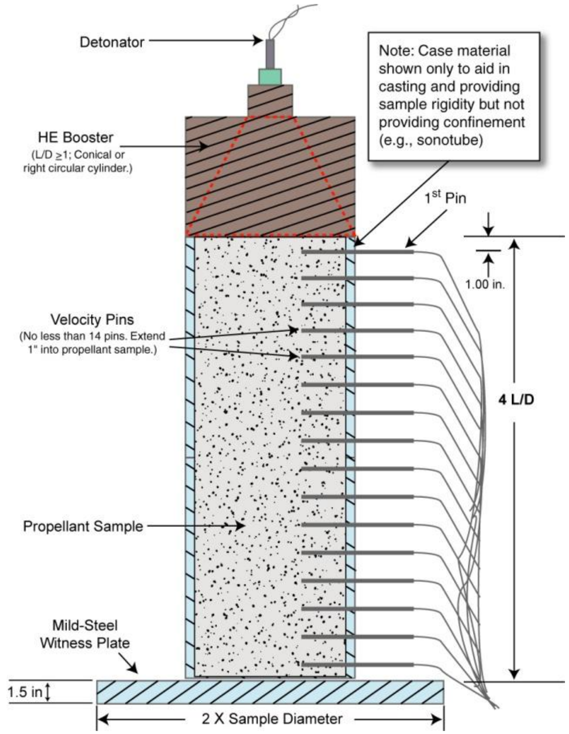
*MAY BE MACHINED FROM WELDED CARBON STEEL TUBING (1026) DRAWN OVER MANDRES (DOM), SPEC: A513

Configurations of TB 700-2 Alternate Gap Tests

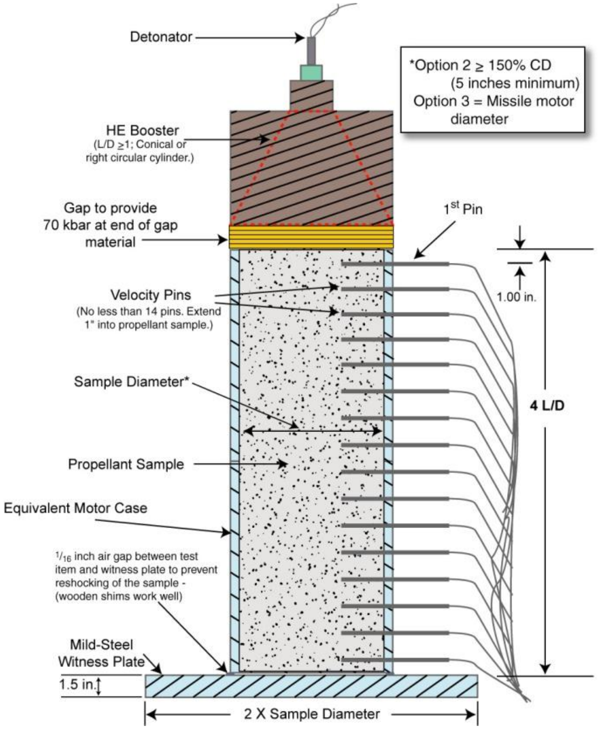


Option 1.

Zero Card SLSGT



Unconfined cylindrical test to determine D_c



Option 2.

$\geq$5" or 150% D_c

70 kbar in Motor Confinement

Option 3.

Motor Diameter

70 kbar in Motor Confinement

Current Revision to TB 700-2

- **First major change is a new "Harmonized" test protocol for obtaining FHC and IM assessment for AE s**
  - **Three tests requiring full-scale test articles in their shipping containers**
    - **UN Test 6(a) Single Package Test** *
    - **UN Test 6(b) Sympathetic Reaction Test** *
    - **UN Test 6(c) Liquid Fuel/External Fire Test**

  ** For rocket motors initiate with an external source approved by JHC & DDESB*

- **Second change is a new protocol for obtaining an IHC for AE**
  - **At a minimum, UN Series 3 or UN Series 4 test results or a rationale why the AE is not forbidden for transportation**
  - ***Additional hazard classification test data may be required to support an IHC of other than HD 1.1. The additional tests will be dependent on the AE configuration and may include tests such as:***
    - **The NOL Card Gap Test , ARDEC Solid Propellant Initiation Sensitivity Test, ELSGT, or SLSGT**
  - **Analogies to existing AE with FHC may be used for assigning IHC**

Final Hazard Classification Test Protocol (HDs 1.1,1.2.1.3 and 1.4) 1998 vs. 2007 Revision

- **Standard UN Test Series 6 (full size) each tested 3 times**
  - **Single Package Test**
    - **Test substance packed as it will be shipped**
    - **1st Trial: #8 blasting cap (0.5 g explosive) to initiate internally**
    - **2nd, 3rd Trials: ignite internally**
      - **Use article's own ignition device (for rocket motors, it can be a static test**
      - **Class 1.1 if package explodes**
  - **Stacked Test**
    - **Substance packed as it will be shipped**
  - **Bonfire Test**
    - **Substance packed as shipped**

- **Standard UN Test Series 6 (full size) each tested 3 times**
  - **Single Package Test**
    - **Test substance packed as it will be shipped**
    - **1st Trial: *For rocket motors initiate with an external source approved by JHC & DDESB***
    - **2nd, 3rd Trials: ignite internally**
      - ***For rocket motors initiate with an external source approved by JHC & DDESB***
      - **Class 1.1 if package explodes**
  - **Stacked Test**
    - **Substance packed as shipped**
  - **Bonfire Test**
    - **Substance packed as shipped**

Current Revision to TB 700-2 Changes of Concern

- **The first change of concern is for both the UN Test 6(a) Single Package and UN Test 6(b) Sympathetic Reaction Tests**
  - ***For rocket motors and artillery propelling charges, initiate the donor with an external source approved by JHC and DDESB***
    - **Static test firing no longer allowed for rocket motors**
    - **The Air Force JHC stated the external initiation sources that DDESB/JHC are considering for this test is a Shape Charge Jet (SCJ)**
    - **DDESB/JHC have also considered using a Rocket Propelled Grenade (RPG) for the external initiation source test**
  - **This change significantly raises the external stimulus applied to the test articles for a threat that is clearly not credible for a storage and transportation threat**
    - **SCJ and RPG threats are credible only for battlefield (IM) and terrorist scenario**

Current Revision to TB 700-2 Changes of Concern (cont)

- **The second change of concern is for the new protocol for obtaining an IHC for AE**
  - ***Additional hazard classification test data may be required to support an IHC of other than HD 1.1. The additional tests will be dependent on the AE configuration and may include tests such as:***
    - **The NOL Card Gap Test , ARDEC Solid Propellant Initiation Sensitivity Test, ELSGT, or SLSGT**
  - **Under the old IHC protocol, the NOL card gap test was used as the discriminator between HD 1.1 and HD 1.3 for assigning an IHC to AE**
    - **It is now up to the JHC**
  - **JHC and DDESB have expressed concerns with using the NOL card gap test results for hazard classification stating that it does not adequately address D_c concerns**
  - **The new change to the IHC protocol paves the way for more stringent shock test requirements**
  - **This should be a wake-up call for all propellant development efforts that claim a HD 1.3 formulation based on the old NOL card gap test results of HD 1.3 at $\leq$ 69 cards.**

Potential Changes of Concern for Hazard Classification

- A potential change of concern is the apparent trend toward DDESB/JHC becoming more conservative in granting FHCs and IHCs
  - In a conversation with the Air Force representative of the JHC, he stated that some members of DDESB are opposed to recognizing an IHC of other than HD 1.1 for substances (propellants)
    - Unless the candidate propellant has passed a shock test or D_c test at the largest diameter of the container they could be cast into
  - The conservative trend was demonstrated when the U.S. Air Force Academy (USAFA) applied for an IHC for their composite cased, HTPB/AP/Al, Falcon rocket motor
    - The relatively low solids loading (~84%) formulation contains no nitramines or other energetic ingredients
      - With the typical D_c of a generic HTPB/AP/Al formulation being >50 inches, there is nothing about this formulation that should raise any concern about $D_{c,}$ with a motor diameter of <7 inches
      - The JHC wanted a parent formulation that had passed the SLGT to be used for the classification by analogy

Potential Impact to the Solid Rocket Community

- **This proposed change to the IHC protocol could have a very serious impact on the solid rocket community involved with R&D of solid rocket propellants and motors**
  - **DDESB requires all DoD facilities to have either a FHC or an IHC for all explosive items stored there**
  - **More stringent and costly requirements to obtain an IHC of other than HD 1.1 will greatly impact R&D operations for new solid propellants and energetic ingredients**
    - **If forced to perform a SLSGT or sample diameter size shock test on every candidate formulation made in R&D laboratories, the cost and resources required would be cost prohibitive**
      - **Requires 82 pounds of propellant (5-gal mixer) and ~$20K/test**
      - **Not all test facilities have the capability of running a SLSGT**
    - **The alternative of accepting an IHC of HD 1.1 on candidate formulations is out of the question due to the much more stringent quantity distance (QD) requirements for HD 1.1 vs. HD 1.3 propellants**
    - **If all new candidate formulations were treated as HD 1.1, most R&D facilities could not comply with the increased QD requirements**

Summary

- The FHC changes significantly raise the external stimulus applied to the test articles for a threat that is not credible for a storage & transportation threat
  - SCJ and RPG threats are credible only for battlefield (IM) and terrorist scenario
  - The proposed changes will add significant cost to a test series that already costs several million dollars to run
- The departure from using the NOL card gap test as the discriminator between HD 1.1 and HD 1.3 for an IHC
  - Will add significant cost to a test series (> order of magnitude)
  - Will cause operational restrictions
- The opposition to giving an IHC of other than HD 1.1 to substances unless the candidate substance has passed a shock test or D_c test at the sample size
  - Has serious implications and shows the DDESB/JHC trend toward more stringent shock stimulus testing to receive a HD 1.3 classification

Recommendations

- The key to getting more credible hazard classification protocols is to give DDESB/JHC test data they can use to make more informed decisions
- With the majority of the changes to TB 700-2 addressing shock and initiation stimulus, it is clear this is a major area of concern
  - The way forward to hazard classification protocols more indicative of credible storage and transportation threats could be accomplished by
    - Conducting shock sensitivity and critical diameter tests on families of propellants at varying levels of shock stimulus and level of confinement
  - If the solid propulsion community is willing to invest in this research, it could have a great potential for return in terms of cost reduction and increase in performance